SAM-FE-BR-TR-2005-0002

UNITED STATES AIR FORCE SCHOOL OF AEROSPACE MEDICINE

Effects of Positive Acceleration on Corneal Stability in Photorefractive Keratectomy (PRK) Subjects

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June 2005

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
07-06-2005	FINAL REPORT	Nov 1998 - Apr 2002

4. TITLE AND SUBTITLE

Effects of Positive Acceleration on Corneal Stability in Photorefractive Keratectomy (PRK) Subjects

5a. CONTRACT NUMBER N/A

5b. GRANT NUMBER N/A

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

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5d. PROJECT NUMBER 77558203

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

USAF School of Aerospace Medicine, Clinical Sciences Division
Ophthalmology Branch (USAFSAM/FECO)
2507 Kennedy Circle, Brooks City-Base TX 78235-5116

8. PERFORMING ORGANIZATION REPORT NUMBER

SAM-FE-BR-TR-2005-0002

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Distribution Statement A: Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This study was a unique aeromedical investigational into the impact of high +Gz exposure on the human cornea on both untreated and treated subjects after photorefractive keratectomy (PRK). It is the first published scientific report to examine corneal stability using advanced technology to evaluate normal and post PRK corneas effects as a consequence of high +Gz levels associated with high performance military aircraft. To examine corneal stability of untreated and treated eyes, repeated data collections were accomplished prior to and at defined time intervals following surgical treatment. Analyzed data found that all ocular surface and refractive measures captured did not significantly differ between untreated and PRK treated subjects under +Gz exposure up to +9 Gz sustained or associated with common air combat maneuvers. Visual acuity, while found to be significantly decreased overall with exposure to high +Gz, did not significantly differ between untreated and treated subjects. It is believed that vibration induced effects were the primary factor causing this. More specifically, PRK subjects performed no differently than non-PRK subjects on visual acuity challenges in this study.

15. SUBJECT TERMS

Aerospace ophthalmology, visual standards, refractive surgery, photorefractive keratectomy, acceleration, PRK, vision in aviation, and eye problems in aviation

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Ronald C. Tutt, Major, USAF, BSC
Unclassified	Unclassified	Unclassified	SAR	32	19b. TELEPHONE NUMBER *(Include area code)*

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18
Adobe Professional 7.0

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EFFECTS OF POSITIVE ACCELERATION ON CORNEAL STABILITY IN PHOTOREFRACTIVE KERATECTOMY (PRK) SUBJECTS

SUMMARY

This study was a unique aeromedical investigational into the impact of high +Gz exposure on the human cornea on both untreated and treated subjects after photorefractive keratectomy (PRK). It is the first published scientific report to examine corneal stability using advanced technology to evaluate normal and post PRK corneas effects as a consequence of high +Gz levels associated with high performance military aircraft. To examine corneal stability of untreated and treated eyes, repeated data collections were accomplished prior to and at defined time intervals following surgical treatment. Analyzed data found that all ocular surface and refractive measures captured did not significantly differ between untreated and PRK treated subjects under +Gz exposure up to +9 Gz sustained or associated with common air combat maneuvers. Visual acuity, while found to be significantly decreased overall with exposure to high +Gz, did not significantly differ between untreated and treated subjects. It is believed that vibration induced effects were the primary factor causing this. More specifically, PRK subjects performed no differently than non-PRK subjects on visual acuity challenges in this study.

INTRODUCTION

Approximately 40% of aircrew require vision correction to qualify for flight duties. Refractive errors result from a mismatch in the optical components (crystalline lens and cornea) and the physical dimensions (size and contour) of the eye. The higher-than-required optical power and/or a relatively large eye produce a myopic or nearsighted refractive error, while lower-than-required optical power and/or a relatively smaller eye contribute to hyperopia or farsightedness. Uncompensated deviation from spherical symmetry of these components results in non-uniform image formation on the retina known as astigmatism.

Correction of vision anomalies can be accomplished in most aircrew by use of spectacles, contact lenses, and/or, recently approved corneal refractive surgery (CRS). Each form of vision correction has associated benefits and limitations. Spectacles are fixed in place relative to the full range of eye movement. As aircrew scan their environment, such as “checking-six,” their point of regard may be beyond the edge of the spectacle lens. A contact lens moves the corrective optics in conjunction with the aviator’s eye, avoiding this limitation from spectacles. Unfortunately, not all aircrew can be adequately corrected with contact lenses. Further, there may be comfort and/or health issues that preclude their use.[1, 2] CRS creates a permanent change in the shape of the corneal surface that alters the refractive status of the eye in order to reduce dependence on corrective eyewear. The resulting corneal based optical correction can potentially correct refractive errors equal-to or better-than spectacles or contact lenses without their limitation. However, CRS is limited in the range of treatable refractive errors. Additionally, CRS is elective surgery that is not indicated in all aircrew for a variety of reasons, to include ocular and systemic medical contraindications, technical limitations, and personal choice.[3-9]

Research on a variety of CRS procedures intended to eliminate or reduce dependency on spectacles or contact lenses has been undertaken for many years. One of the earliest CRS procedures, Radial keratotomy (RK) attempted to correct refractive errors by creating deep radially orientated incisions that weakened the cornea and resulted in central flattening of the corneal contour. This procedure also permanently weakened the cornea and resulted in corneal haze, ocular glare, diurnal refractive instability, chronic hyperopic shift, and changes in refractive error caused by changes in altitude.[3] Consequently, RK was not approved for military aircrew.

At the time of this study, however, photorefractive keratectomy (PRK) was under consideration for use in AF aircrew. PRK uses a 193 nanometer (ultraviolet C) excimer laser to modify the optical powers of the eye by ablating corneal tissue in selective areas. In myopia, this ablation creates central corneal flattening that reduces the overall refractive power of the cornea. Paracentral ablations are used to steepen the central cornea in hyperopia while non-uniform ablations enables correction of limited degrees of astigmatic refractive errors. The PRK technology approved for this study conformed with FDA approval guidelines which allowed only uniform central corneal ablations for myopia, but which also resulted in a limited amount of astigmatism correction. Subjects for this study were selected to match this treatment limitation.

Although PRK is widely accepted clinically, CRS research studies to date have not adequately addressed concerns regarding the aeromedical and operational impact of such surgery. Those concerns are of high interest within the military as CRS gains appeal and may offer advantages useful in military aviation.[3-5] Although a more successful clinical procedure than RK, PRK nonetheless is a permanent surgical alteration of the cornea that may also generate undesirable side effects, such as disruption of collagen fibers that induces chronic long term corneal instability and pathogenic responses, such as scarring and haze, that produces glare and other visual performances changes, that may have unacceptable consequences for military operations. In addition, the unique conditions associated with military operations may present additional issues that have not been addressed by general clinical research studies or may manifest only when stressed under austere or extreme military settings.

In particular, there has been no research to date that has addressed high-G concerns, specifically, the effect of acceleration on corneal morphology and surface characteristics following CRS procedures, including PRK.

High performance aircraft commonly expose aircrew to rapid onset of high levels of acceleration force. Acceleration forces can occur in any or combination of axes (Figure 1) relative to the human body.

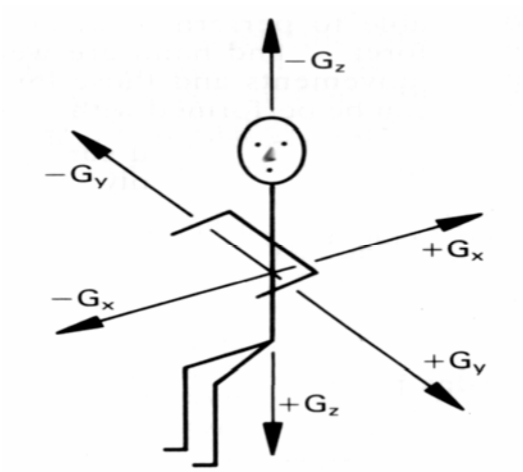

Figure 1: Representation of directional gravitational forces ("G")

Acceleration in a given direction gives rise to a gravitational equivalent (G) force vector in the opposite direction of the acceleration vector. Front-to-back (forward) acceleration in the "x" axis creates a G force pressing aircrew back in their seats (+Gx). Similarly, back-to-front (backward) acceleration presses aircrew forward against their seat straps (-Gx). Lateral acceleration creates lateral gravitational force to the airman's left (+Gy) or right (-Gy). The acceleration focus of this study is in the "z" axis (Gz), a commonly experienced gravitational equivalent force pressing down (+Gz) or up (-Gz). Significant levels and combinations of these axial accelerations are experienced in military aircraft. While G forces in any axis have noticeable effects, the Gz axis represents a particular aeromedical concern due to its routine

operational occurrence and its attendant effects on blood flow.[10] In addition to anti-G flight ensembles, aircrew are also trained in physical countermeasures to minimize the loss of cerebral blood flow when exposed to downward gravitational forces (+Gz). Since +Gz can impact spectacle frame and contact lens stability during flight, PRK presented a method to potentially reduce or eliminate aircrew dependence on eyewear. Prior to this study, however, there was only one published preliminary research study that evaluated the effects of +Gz acceleration on normal corneas.[10] However, prior to this study, there were no published studies of acceleration effects in corneas post-PRK.

One of the issues regarding PRK treatment for myopic military personnel is the cost vs. benefit of gaining some level of independence from full-time spectacle or contact lens wear. Multiple in-flight stressors and environmental factors can render standard vision correction methods inadequate or problematic. For example, spectacle lenses are difficult to keep clean, free of fogging and sweat, and in place at all times, particularly in aircrew exposed to changing gravitational force vectors. Lateral and vertical G forces can displace optical correction in several different directions. Further, standard eyewear temples and earpieces can create areas of focal irritation, so-called "hotspots," under helmets, headsets, and other headgear. Vision at extreme ranges of gaze is degraded as the line of sight moves beyond the spectacle lens edge. This becomes more critical in high performance aircraft that require looking backward ("check-six"). While contact lenses overcome many of these particular spectacle complications, they are not without limitations of their own.[1, 2] Corneal irritations, infections, and lens displacements associated with contact lenses can directly impact mission readiness. Additionally, contact lens support materials, such as cleaning, disinfecting, rinsing solutions, backup contact lenses and spectacles, increase the logistical demands during deployment. While soft contact lenses have been proven to be more stable under +Gz, rigid contact lenses have not.[1, 2] In addition, all contact lenses can displace involuntarily creating a sudden degradation of vision and stereopsis. Additionally, not all aviators are medically compatible with or elect to wear contact lenses.

Consequently, problems associated with spectacles and contact lenses in the operational environment may reduce visual performance at a critical time, potentially impacting flight safety and mission outcomes. PRK treatment for myopia is viewed as an alternate military vision correction method which may eliminate or minimize the use of spectacles and/or contact lenses, thereby providing enhanced mission readiness. CRS may also widen the potential aircrew candidate pool by allowing applicants previously excluded based on levels of unaided visual acuity and refractive errors that exceed qualification criteria, to potentially be considered for military aviation careers.

PURPOSE

This study investigated the effect of acceleration (+Gz) on corneal morphology and visual performance prior to and following myopic photorefractive keratectomy (PRK). The protocol was specifically designed to provide an initial assessment of corneal stability under levels of +Gz likely to be encountered in military aviation.

This acceleration study was a research subset of the overall USAF PRK research program conducted to support the USAF/CC directed USAF School of Aerospace Medicine and AFRL aviation PRK study at Brooks AFB, TX to investigate the aeromedical and operational impact of PRK on myopic active duty USAF personnel. Lessons learned were to be used to base future research and aeromedical policy with respect to PRK.

SUBJECTS

From a pool of over 300 subjects qualified to participate in an overall USAF PRK study, a subset of twenty-five non-flying active duty USAF personnel were selected and ultimately qualified for this acceleration study. However, seven of the selected subjects failed to reach preoperative G training goals and were dropped from the study prior to PRK treatment. As a result, eighteen non-flying subjects (17 males and 1 female) ranging in age from 20 yrs to 42 yrs completed all training and post-surgical requirements for this study. The voluntary, informed consent of the subjects used in this research was obtained as required by AFI 40 - 403. Study briefings covering experimental procedures and hazards associated with acceleration were accomplished prior to participating in the acceleration study.

Subjects were medically qualified as centrifuge test subjects and trained in accordance with AFRL/HEP centrifuge training protocols. The study required a training level and tolerance to complete two repetitions of rapid onset profiles (a series of 15-sec plateaus) at +3, +5, +7, and +9 Gz. Subjects also trained on one of two Simulated Air Combat Maneuver (SACM) profiles. All subjects were required to wear standard anti-G suit or ATAGS (Advanced Technology Anti-G Suit) with COMBAT EDGE (Combined Advanced Technology Enhanced Design G-Ensemble) during G exposures depending on the SACM protocol performed. Subjects using COMBAT EDGE were trained in pressure breathing techniques at ground level, if not already proficient.

The acceleration study spanned between 14 Nov 1998 to16 Apr 2002. It included a comprehensive baseline ophthalmological examination, 4-6 week period of preliminary centrifuge training, pre-treatment +Gz baseline, post-treatment 6-, 12-, and 24-month follow-up centrifuge data collections. Subjects served as their own within subject study control, by comparing pre- and post-PRK treatment performance data. Due to the physically demanding nature of high-Gz exposure, the 24-month data collection period, and various military non-study administrative requirements, a limited number of subjects were able to complete all data collection points defined in the study's protocol. The number of subjects at each centrifuge milestone is presented in Figure 2.

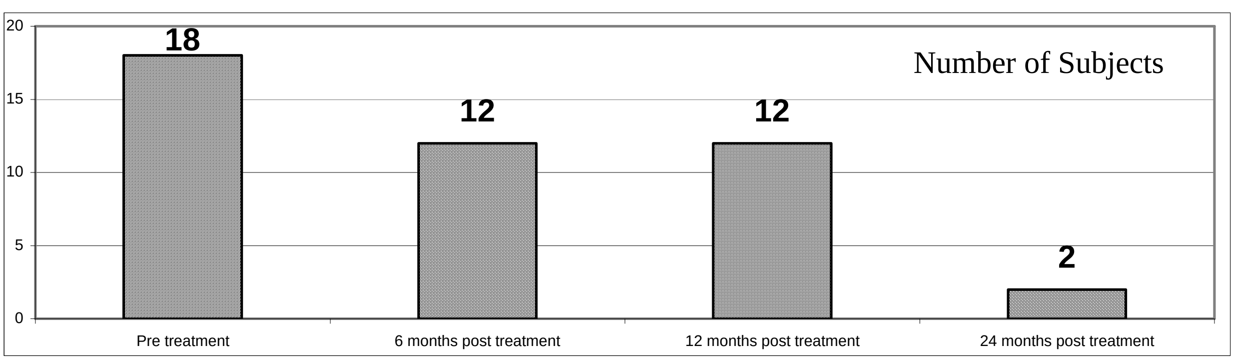

Figure 2: Number of subjects completing each data collection point.

FACILITIES AND EQUIPMENT

AFRL/HEP CENTRIFUGE

The AFRL/HEP centrifuge (Figure 3) used for this project was located on Brooks AFB, TX. The centrifuge is designed to simulate the cockpit environment in modern high performance USAF aircraft. The attached gondola has a regulation aircrew seat secured in a similar configuration used in high performance aircraft. The seat angle used was determined by the particular SACM being studied. The gondola was attached to a 6.1-meter (20 foot) rotor arm. The centrifuge is powered by four electrical motors. The combined power of these motors produces 1,000 horsepower, providing maximum capability of +6 Gz/second acceleration and sustained +30 Gz (unmanned). While manned, the centrifuge is approved to +12 Gz. This study limited exposure of subjects to a maximum of +9 Gz.

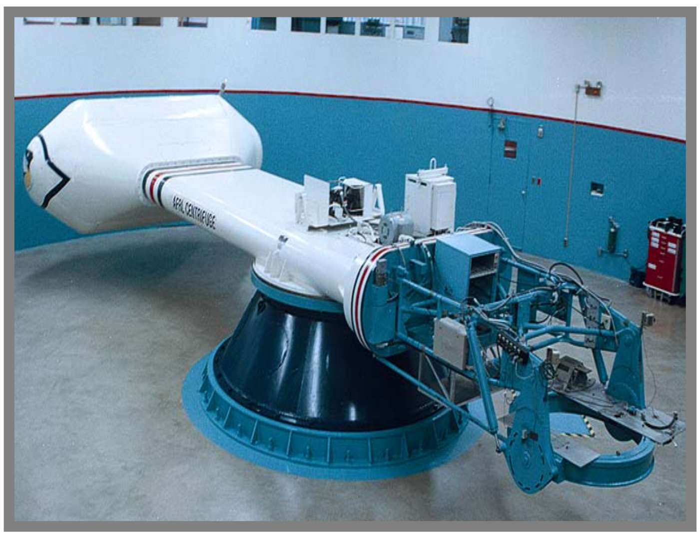

Figure 3: AFRL Centrifuge at Brooks AFB, TX

METHODS

ANTI-G TRAINING AND EQUIPMENT

All subjects were fitted with a standard anti-G suit (CSU-13 B/P) and MBU-12/P mask for initial training. Subjects were initially assessed for G tolerance and subsequently selected to perform one of two SACM protocols: 1) +4.5 to +7 Gz (4-7 SACM) in a 13-degree tilt back seat, or 2) +5 to +9 Gz (5-9 SACM) in a 30-degree tilt back seat. Subjects identified to perform the 5-9 SACM profile were fitted with ATAGS and COMBAT EDGE, which included the HGU-55/P helmet, MBU-20/P mask, COMBAT EDGE chest counter pressure garment, regulator, and G-valve. Further, subjects using COMBAT EDGE were trained in pressure breathing techniques at ground level, if not already proficient. Subjects identified to perform the 4-7 SACM profile wore the standard anti-G suit/mask combination and were not required to complete pressure breathing training. Efforts were made to select equal number of subjects performing each SACM profile.

+Gz PROFILES

During initial centrifuge training, subjects performed "Relaxed Gradual Onset Runs." These slow onset +Gz (+0.01 G/sec) evaluations, accomplished with the anti-G ensemble inactivated, established individual baseline relaxed +Gz tolerances. During subsequent training and data collection, subjects with activated anti-G suit protection and anti-G straining techniques, as needed, performed a series of "Rapid Onset Runs" to 15 seconds of sustained of +3, +5, +7, or +9 Gz. A diagrammatic representation of the different runs is illustrated below (Figure 4). During data collection, subjects accomplished two consecutive runs at each +Gz level.

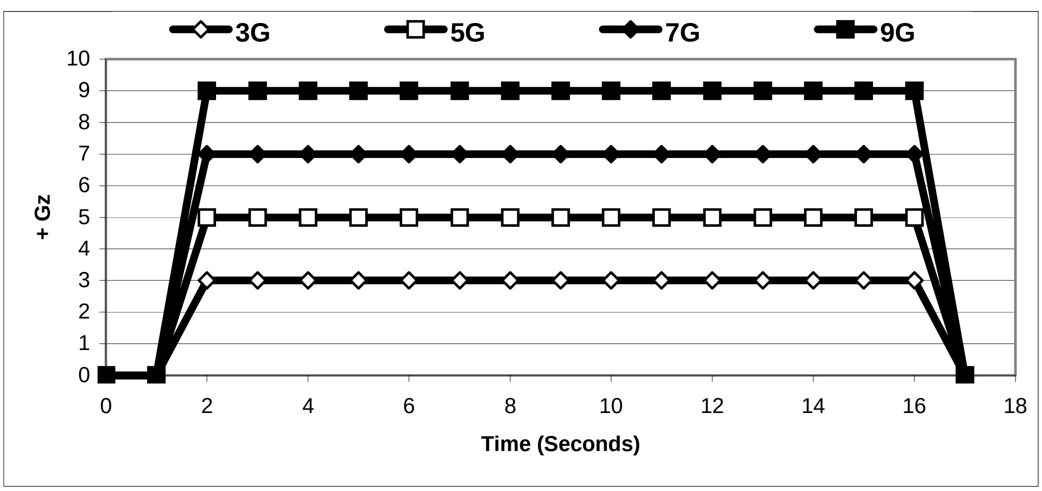

Figure 4. Rapid onset runs: +6 Gz/second onset for 15 seconds

Following the "Rapid Onset Runs," subjects accomplished either the 4-7 SACM (Figure 5) or the 5-9 SACM (Figure 6) profile based on their individual +G tolerance and training. The 4-7 SACM profile cycled every 15 seconds between +4.5 and +7 Gz for a minimum of 1 complete cycle. The +5 to +9 Gz SACM cycled every 10 seconds for a minimum of 1 cycle. During data collection, subjects accomplished two consecutive SACM runs.

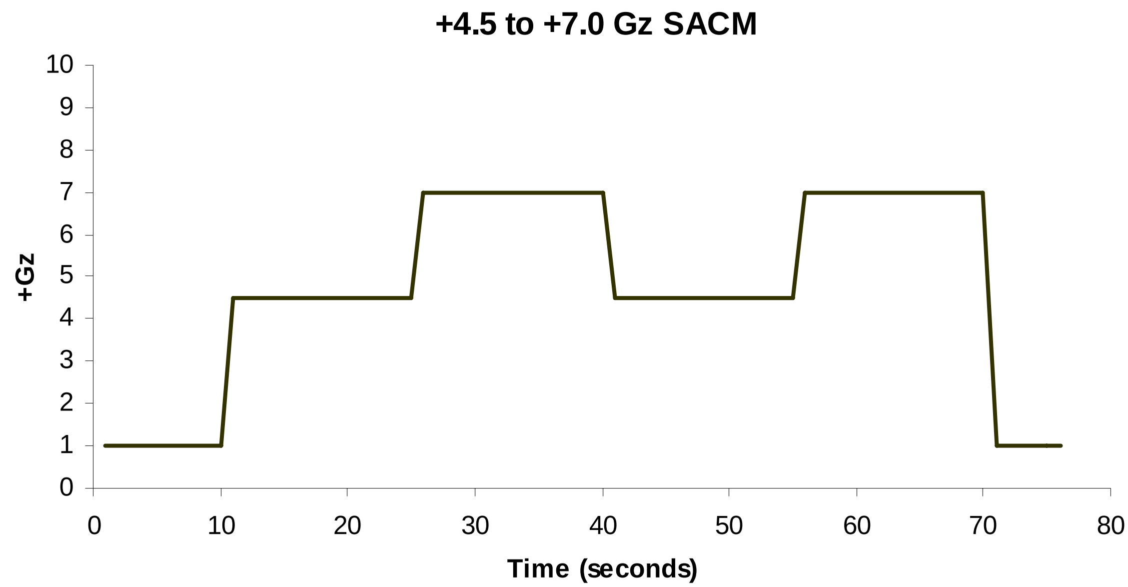

Figure 5. Simulated Air Combat Maneuver (SACM) profiles: Rapid onset (+6 Gz/second) to +4.5 Gz, followed by rapid + Gz onset to +7 Gz, repeated 1 - 3 additional peaks.

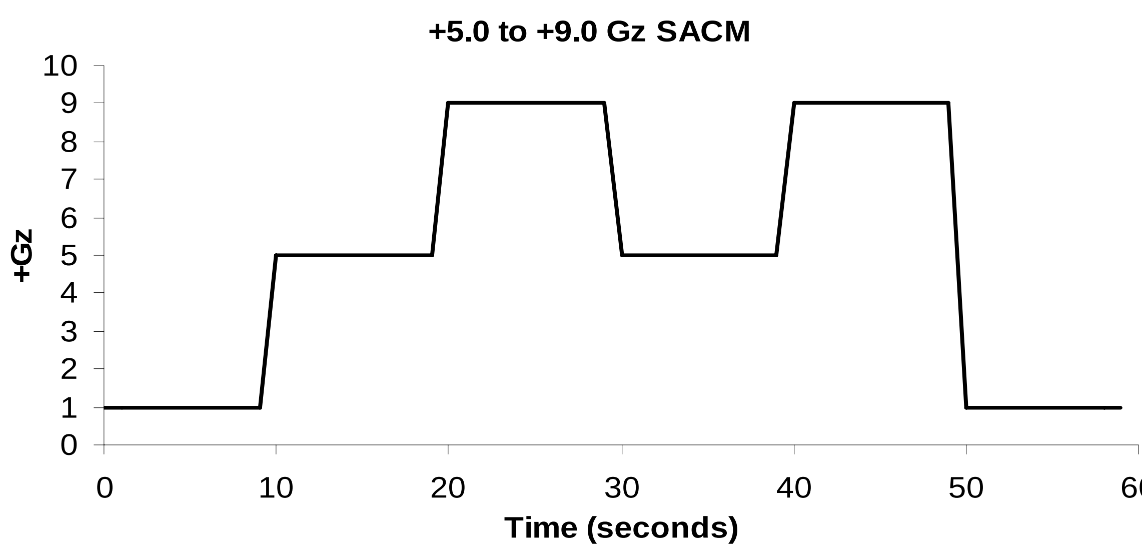

Figure 6. Simulated Air Combat Maneuver (SACM) profiles: Rapid onset (+6 Gz/second) to +5 Gz, followed by rapid +Gz onset to +9 Gz, repeated 1 - 3 additional peaks.

OCULAR PERFORMANCE

Standard aircrew spectacles (HGU-4/P) were fabricated for each subject prior to data collection based on current refractive error that achieved best-corrected visual acuity, if required. Visual acuity was assessed utilizing a standard high contrast visual acuity Snellen letter chart. Monocular visual acuity data was captured at last peak +Gz exposure of each profile. All subjects completed two runs at each profile to enable monocular visual acuity data for right and left eyes.

The “LIGHTHOUSE NEAR VISUAL ACUITY TEST, Second Edition” (Figure 7) was set at a calibrated distance from the subject in the centrifuge gondola. This high contrast acuity chart remained fixed in position and was illuminated by the centrifuge interior lighting. The true visual acuity demand was calculated for each subject based on their eye to chart distance (calibrated distance, average 83 cm or 32.5 inches) A “drop-down” door hid the chart letters from view until the door was remotely lowered by an observer upon attaining the target +Gz level.

Figure 7: LIGHTHOUSE NEAR VISUAL ACUITY TEST, Second Edition

Subjects viewed the high contrast visual acuity chart at peak +Gz and reported the smallest recognizable letters. At baseline and during low +Gz levels, the subjects were able to verbalize visual acuity data at peak +Gz. At higher +Gz levels, vocalization was difficult, or impossible, due to focused attention on sustaining anti-G straining maneuvers to remain conscious. If the subject was unable to talk during peak +Gz exposure, they were instructed to view the acuity chart at peak +Gz, determine their minimum readable letters, and report their visual acuity during the immediate post-G period.

Corneal and refractive data were captured immediately after G exposure with non-invasive automated keratometric, topographic, and corneal refractive instruments used routinely at the USAF School of Aerospace Medicine, Aeromedical Consultation Service (ACS), Ophthalmology Branch, Brooks Air Force Base TX. Post clinical experience with corneal changes from high +Gz or eye rubbing identified that any significant induced corneal

morphological changes would not be fleeting and would persist for many minutes to hours after such an event.[10] Refractive, topographic, and keratometric data began within 30 to 120 seconds following each G-exposure and completed on both eyes within 10 minutes.

Corneal topography data was collected using the EyeSys Vista™ HANDHELD CORNEAL TOPOGRAPHER (HCT) (Figure 8).

Figure 8: EyeSys Vista™ HANDHELD CORNEAL TOPOGRAPHER

Two corneal topography measures of the eye under +Gz were accomplished with the HCT within the gondola immediately after each run. The first was captured within 30-45 seconds after each +Gz exposure; the second, 1-2 minutes later. The corneal topography data was downloaded onto a laptop computer, processed using proprietary EyeSys software, and later printed to hardcopy. Specific data measures were subsequently transferred to a central database for statistical analysis.

Auto-Refraction and Auto-Keratometry data were simultaneously acquired in the gondola using a RETINOMAX K-PLUS AUTO REFRACT-KERATOMETER (Figure 9).

Figure 9: RETINOMAX K-PLUS AUTO REFRACT-KERATOMETER

Two sets of refractive and keratometric readings on both eyes were captured immediately following +Gz exposure and between the topography measures described above. The first pair of readings occurred within 45 secs of gondola stoppage; the second within 1 minute. Data were printed to hardcopy format and subsequently transferred into a central database for statistical analysis.

ANALYSIS

The refractive and keratometric data were analyzed by two methods. The first method is considered a standard method of refractive error analysis utilizing spherical equivalent (sum of spherical and ½ of the cylinder powers). The second method uses polar transformation of refractive data into 3-dimensional coordinates or "Power Vectors." [11]

Power Vector transformation enables statistical analysis of all refractive components, spherical and cylindrical powers, and cylinder axis versus spherical equivalent, which combines spherical and cylinder powers while minimizing effects of concurrent sphere and cylinder changes or axis rotation. The polar coordinates representing the principle refractive powers and orientation are used to calculate a vector length representing the net blurring strength of the spherical and cylindrical powers.

To illustrate the difference between standard analyses of refractive errors versus power vectors, the following example is given. Table 1 lists five typical refractive errors and the resulting values used for analysis. The five refractive errors used in this illustration transform to a spherical equivalent value of –2.50 Diopters (spherical power in Diopters (D) added to ½ of the cylinder power in Diopters). Transforming the same data to "Blurring Strength" (Power Vector transformation) demonstrates a significantly different impact above 1.00 Diopter of cylinder. Note: the net blurring strength reflects the absolute defocus in terms of diopters as opposed to minus or plus spherical equivalent data. A minus direction of blurring was incorporated to allow comparison to the example's spherical equivalent transformation.

Table 1: Power Vector "Blurring Strength" and standard "Spherical Equivalents." Five common refractive error and typical analysis transformations.

Sphere (D)	Cylinder (D)	Axis (degree)	Spherical Equivalent	Blurring Strength
-2.50	0.00	180	-2.50	-2.50
-2.25	-0.50	180	-2.50	-2.51
-2.00	-1.00	180	-2.50	-2.55
-1.50	-2.00	180	-2.50	-2.69
-1.00	-3.00	180	-2.50	-2.92

Figure 10 presents this data comparison graphically. The left graph compares the dioptric power of Spherical, Cylinder, Spherical Equivalent, and Blurring Strength. The right graph compares the percent change between resulting spherical equivalent and blurring strength transformations.

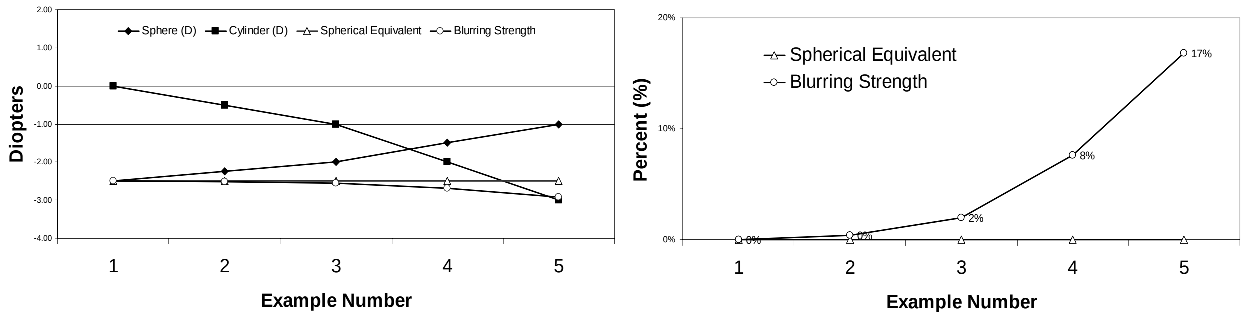

Figure 10: Power Vector vs Spherical Equivalent representation

From this example set, it is apparent the contributions of high amounts of cylinder power or high amounts of change in cylinder power can impact analyses. Cylinder power of 1.00 Diopter or more could contribute 2% or more to the overall data value depending on the transformation used.   For this study population, subjects were refractively screened and limited to a maximum cylinder power of -1.00 Diopters. Therefore, while power vector analysis was accomplished, the contribution of cylinder is not expected to significantly alter the results obtained by either method.

RESULTS

AUTO-REFRACTION

Mean auto-refraction data at each +Gz profile were analyzed by power vector (Blurring Strength) and spherical equivalent (SE) techniques. There was no significant difference found between the two methods. The mean SE data for each of the +Gz and SACM exposures as compared to pre +Gz baseline (BL) are presented in Figure 11.

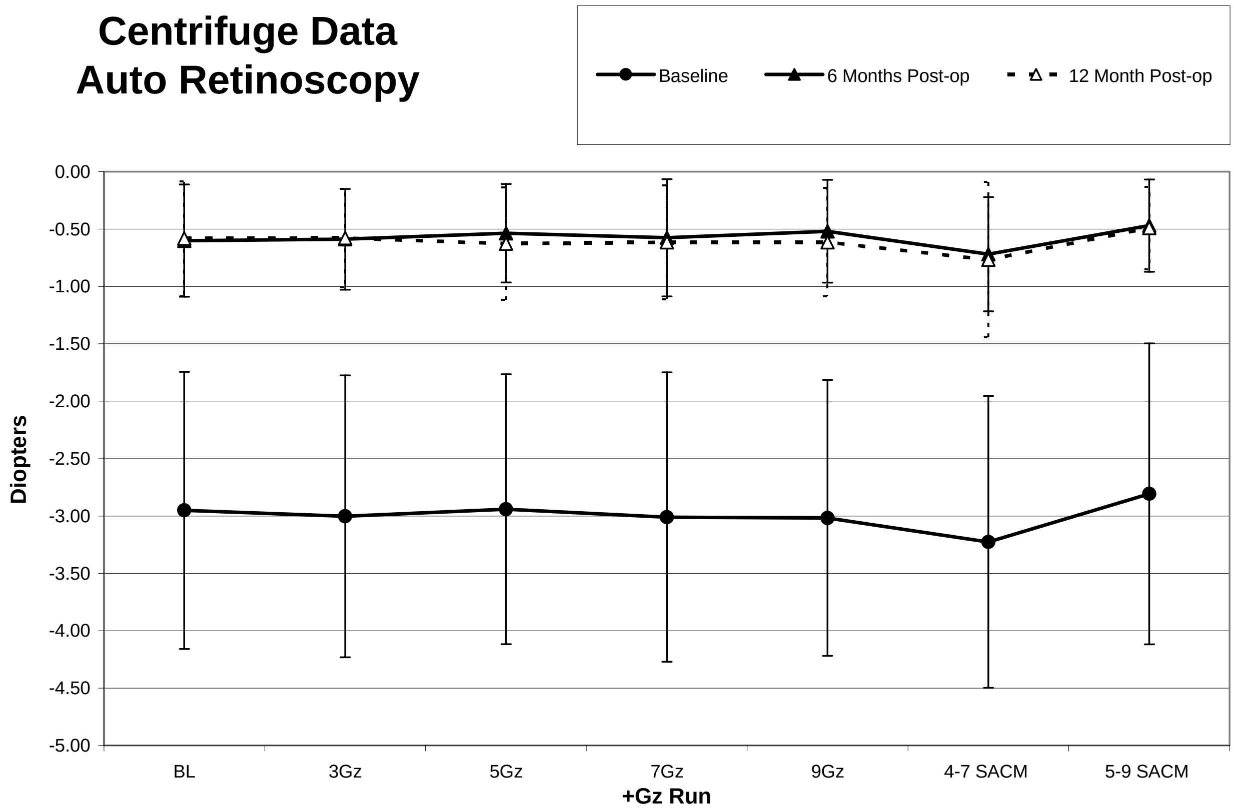

Figure 11: Refractive error change as a function of +Gz Spherical Equivalent (SE)

Statistical analysis of the refractive power vector and spherical equivalent data found no significant change associated with +Gz exposure in either untreated or treated subjects. There were no significant differences observed between the right and left eye refractive data.

AUTO-KERATOMETRY

Mean auto-keratometry data corresponding to Power Vector (mean blurring strength) and Spherical Equivalent at each +Gz profile were analyzed. There was no significant difference found between the two methods. The mean SE auto-keratometry data for each of the +Gz and SACM exposures as compared to pre +Gz baseline (BL) are graphically displayed in Figure 12.

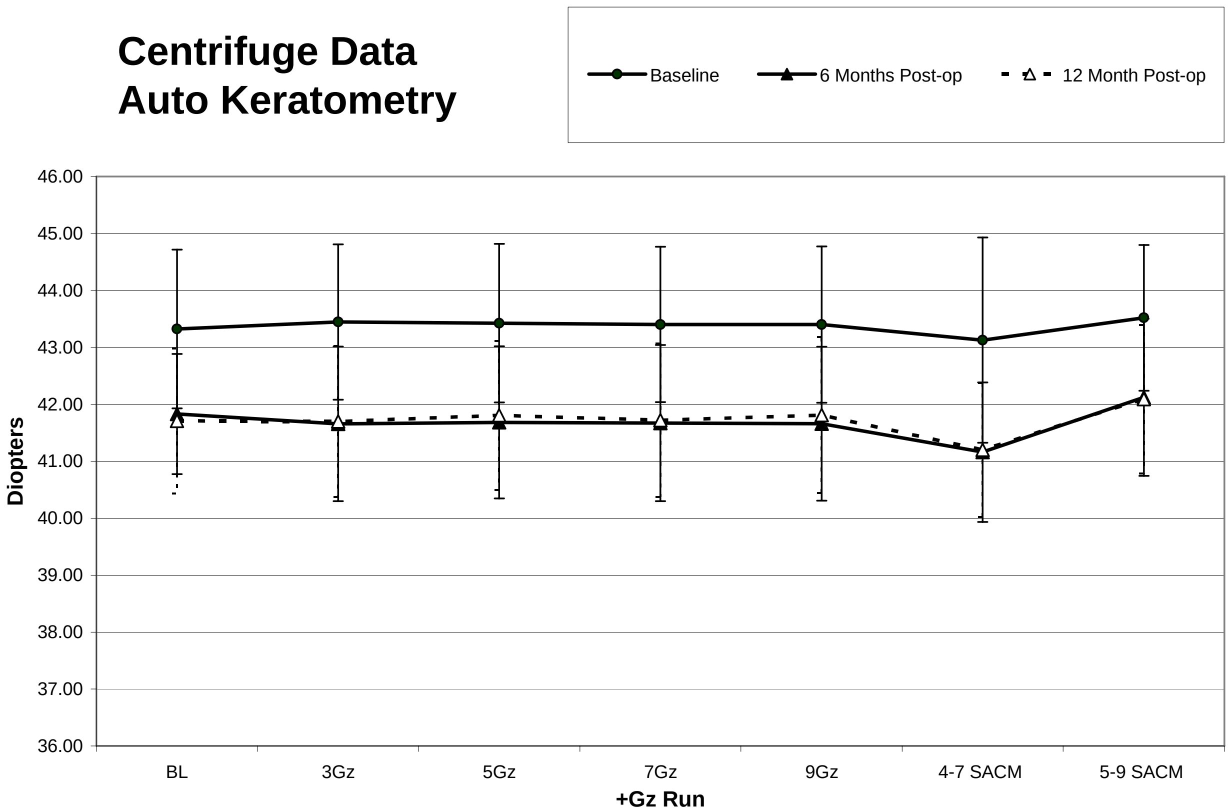

Figure 12: Auto-Keratometry changes as a function of +Gz Spherical Equivalent (SE)

Statistical analysis of the keratometric power vector and spherical equivalent data found no significant change associated with +Gz exposure in either untreated or treated subjects. There were no significant differences observed between the right and left eye keratometric data. There was, however, significant change between pre- and post-keratometric data. This corresponded with the expected alterations of the corneal curvature secondary to excimer ablation.

CORNEAL TOPOGRAPHY

Mean corneal topography and central keratometry data corresponding to Power Vector (mean blurring strength) and Spherical Equivalent presentation for each of the +Gz and SACM exposures as compared to pre +Gz baseline (BL) is displayed in Figure 13. While there were significant changes between pre- and post-keratometric data corresponding to changes induced by excimer ablation, no significant change was found associated with +Gz exposure in untreated or treated subject. There were no significant differences observed between the right and left eye corneal topography data.

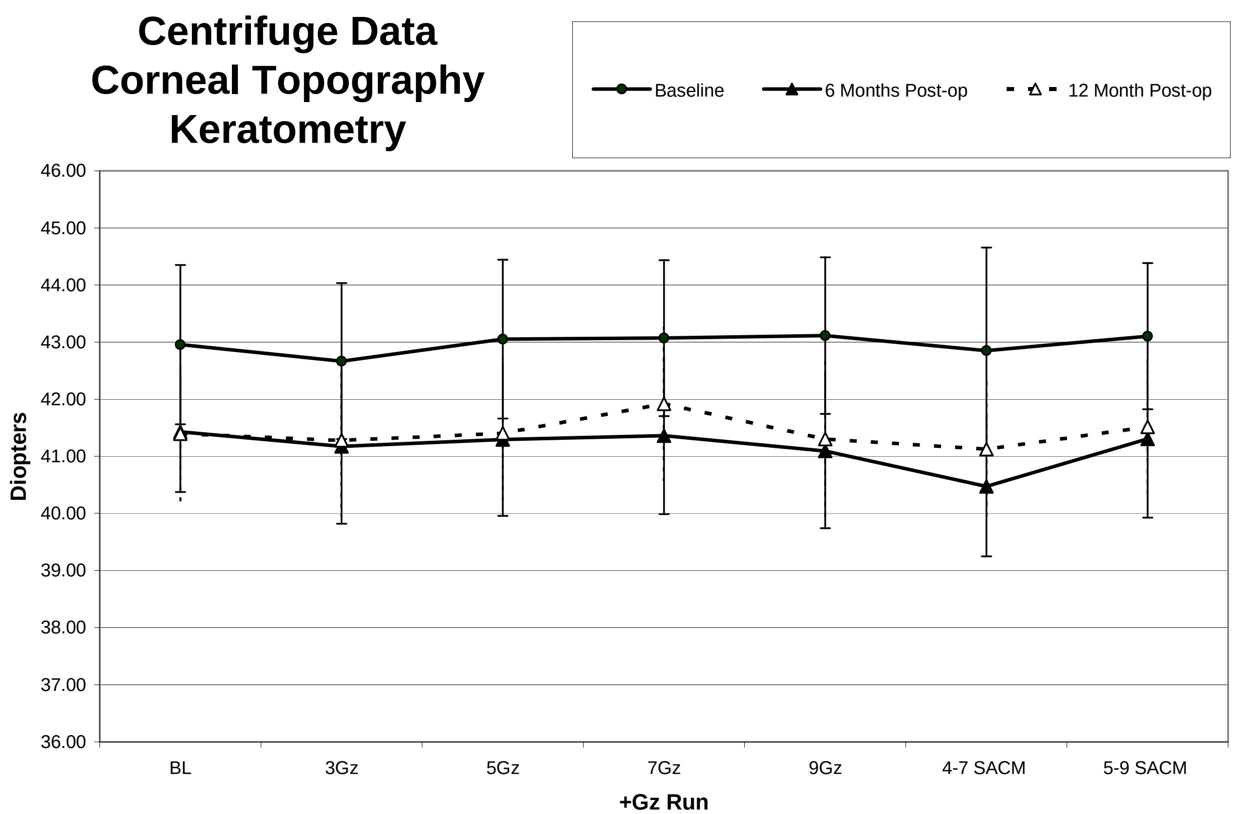

Figure 13: Corneal topography changes as a function of +Gz Spherical Equivalent (SE) vs Power Vector (PV) "Blurring Strength"

VISUAL ACUITY

Mean Snellen visual acuity data for each of the +Gz and SACM exposures as compared to pre +Gz baseline (BL) is graphically displayed in Figure 14. Better visual acuity is represented by a smaller data value. With increasing +Gz force, visual performance degraded in all profile data sets. Visual performance was significantly reduced at all exposures above +3 Gz (+5 Gz +7 Gz, +9 Gz, and both SACM profiles; p=0.05, 0.001, 0.001, 0.0061, 0.001 respectively). No significant difference was found between untreated and treated data under +Gz exposure. However, there was a significant improvement in mean visual acuity performance post-operatively at 6 months and 12 months (p=0.001) over pre-operative data.

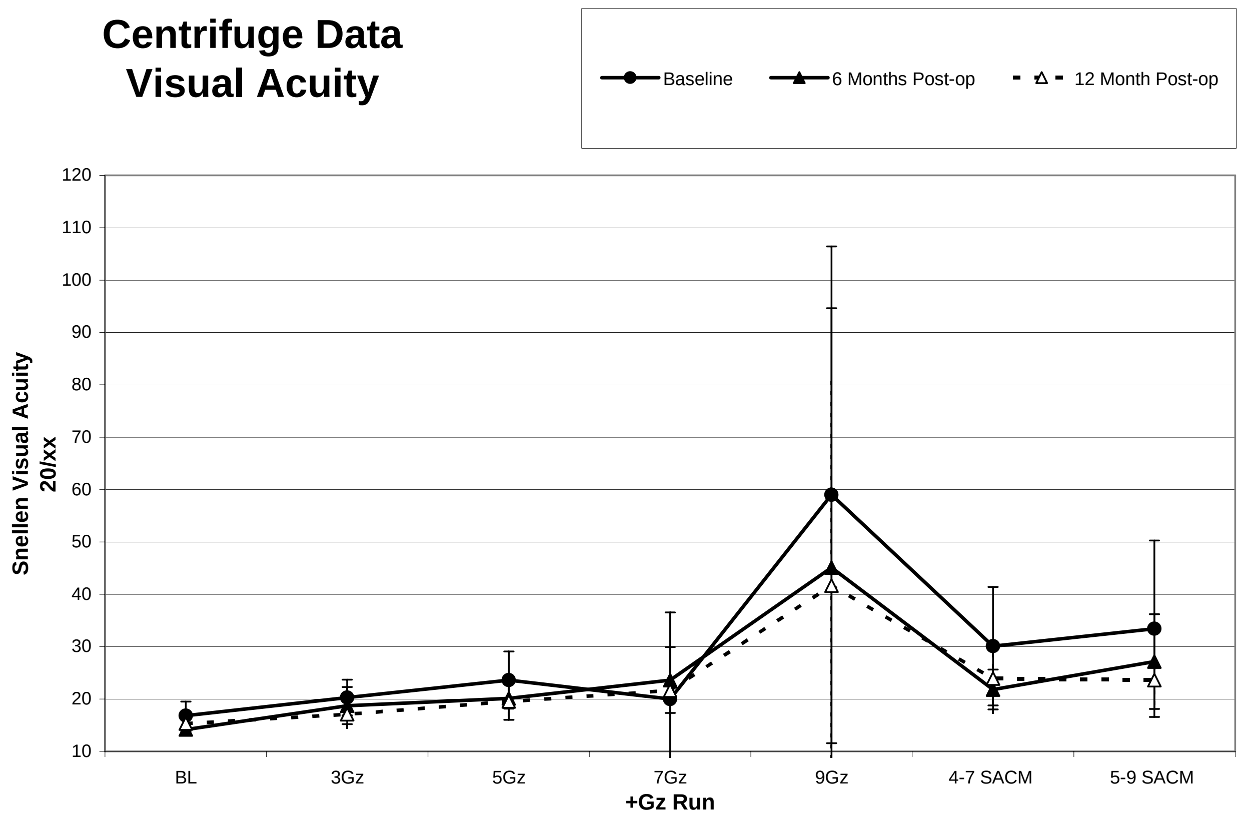

Figure 14: Visual acuity changes as a function of +Gz

DISCUSSION

Two aspects of ocular and visual performance were examined by this study. The first involved the response of the ocular and visual performance under defined +Gz profiles. The second was a comparison between ocular and visual performance before and after undergoing PRK treatment to the myopic cornea.

To examine the effect of +Gz on ocular and visual performance, each subject completed a series of +Gz exposures as described above and had data collected prior to and following PRK treatment. Analysis of pre- and post- treatment ocular measures revealed no significant changes in any of the refractive or corneal measures captured immediately following rapid onset and sustained exposures up to +9 Gz within the designs of this study. In essence, there was no change induced by photorefractive keratectomy.

In contrast, visual acuity performance significantly decreased as +Gz level increased. This occurred above +3 Gz and was significantly reduced, both pre- and post-operatively. The degree of the visual acuity loss occurred in direct proportion to level of +Gz, meaning that increasing +Gz loads resulted in progressively worsened levels of visual acuity. It was, however, noteworthy that most subjects were unable to report any measurable visual acuity data due to the concentrated physical demands required to maintain consciousness during peak +7 and +9 Gz exposures. Reports from subjects indicated the loss of attention to the visual task was limited to just the peak +Gz effort period and that immediately upon completion of the peak, they could clearly recognize the target. However, within the design of this study, the criteria to report visual acuity at peak renders accurate in-flight confirmation of visual acuity at the highest +Gz peaks impossible in these test subjects. In addition, given the relative inexperience of the test subjects in this study, this observation may not necessarily be representative of experienced aircrew performance. The delay in reporting the observed acuity at peak +Gz levels may have impacted reported visual performance, thus enhancing the measured change. None-the-less, visual performance was significantly altered in these test subjects at levels above +3 Gz.

It is well recognized that visual acuity performance under +Gz can be affected by many factors.[1, 3] Unique to the high +Gz environment, a subject's attention is normally prioritized to maintaining consciousness by concentrating effort on effective anti-G straining maneuvers. Therefore, personal criteria for recognizing individual minimum visual acuity may have changed in some subjects while under high-G stress. Furthermore, an inadequately performed straining maneuver would reduce ocular perfusion resulting in hypoxia and potentially related visual performance reductions. Vibration, another factor influencing human visual performance, can create a negative effect on visual acuity.[3] Dissociated vibration between the subject and the target letters of regard can induce a reduction in high frequency acuity. Vibration was an unavoidable effect associated with centrifuge operation, particularly at higher +Gz levels, and parallels that associated in an actual aircraft under high G applications. For this study design, the level of vibration was considered a factor above +3 Gz, but was reproducible and similar at each corresponding +Gz profile. Therefore, within reasonable acceptance, each subject experienced the same degree of vibration corresponding with the exposure level and should have experienced a similar vibration induced decrement.[12] Those vibratory effects were similar whether an individual eye had PRK or not. Therefore, PRK did not influence this effect in any way.

These subjects' ability to perform optimally under +Gz also may vary due to other human performance factors, such as general fatigue and motivation. The research subjects were non-aircrew volunteers with no centrifuge experience prior to this study. By virtue of the comprehensive centrifuge training conducted by the AFRL centrifuge staff and required to facilitate the likelihood of an individual subject to reach the targeted +Gz levels in this study, all subjects were similar in their experience. After PRK treatment, each subject underwent refresher training prior to the first post-operative data collection. However, all of our subjects, while fully trained to perform data collection at study-designed profiles, were not aircrew and therefore not routinely exposed to high +Gz or familiar with how to efficiently perform in that environment. Consequently, subjects may have focused more of their attention on proper anti-G straining maneuvers and as a result, experienced more fatigue and reduced visual attentiveness than experienced aircrew. For these reasons, direct extrapolation of specific visual acuity performance to trained aircrew would not be appropriate. Despite these issues, visual acuity data demonstrated that the visual performance of the study subjects was not significantly influenced by PRK as compared to their individual baseline performances.

CONCLUSIONS

Within the limitations of the experimental design in this experimental protocol, refractive, topographic, and keratometric as measured by the equipment used in this study were not significantly affected in PRK eyes as compared to non-PRK eyes when exposed to +9 Gz and during two different simulated air combat maneuvers. Thus, we conclude that within the limits of this experimental design, PRK eyes performed no differently than untreated eyes up to +9 Gz.

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